Applying the Food Multimix concept for sustainable and nutritious diets.

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Background: Despite a rich and diverse ecosystem and biodiversity, worldwide, more than 2 billion people suffer from micronutrient malnutrition or hidden hunger. Of major concern are a degradation of our ecosystems and agricultural systems which are thought to be unsustainable thereby posing a challenge for the future food and nutrition security. Despite these challenges, nutrition security and ensuring well balanced diets depend on sound knowledge and appropriate food choices in a complex world of plenty and want.

We have previously reported on how the food multimix (FMM) concept, a food-based and dietary diversification approach can be applied to meeting energy and micronutrient needs of vulnerable groups through an empirical process. Our objective in this article is to examine how the concept can be applied to improve nutrition in a sustainable way in otherwise poor and hard-to-reach communities.

We have reviewed over 100 FMM food recipes formulated from combinations of commonly consumed traditional candidate food ingredients; on average five per recipe, and packaged as per 100 g powders from different countries including Ghana, Kenya, Botswana, Zimbabawe and Southern Africa, India, Mexico, Malaysia and United Kingdom; and for different age groups and conditions such as older infants and young children, pregnant women, HIV patients, diabetes and for nutrition rehabilitation. Candidate foods were examined for their nutrient strengths and nutrient content and nutrient density of recipes per 100 g were compared to reference nutrient intakes (RNIs) for the different population groups.

We report on the nutrient profiles from our analysis of the pooled and age-matched data as well as sensory analysis and conclude that locally produced FMM foods can complement local diets and contribute significantly to meeting nutrient needs among vulnerable groups in food-insecure environments.

Key words: food multimix, candidate foods, sustainable, food security, resource-poor, nutrition interventions.

Background

Food-based approaches are increasingly being emphasised as more cost-effective and sustainable ways to improve food security and reduce the prevalence of micronutrient deficiencies(1-7). Applying biofortification, improved varieties of sweet potatoes and bananas have been cultivated and used as part of feeding programmes in poverty alleviation and to tackle vitamin A deficiency in parts of Africa(8-10). However applying these new and improved varieties of foods singly whilst laudable, also attracts criticism for being similar to the single-nutrient approach adopted in the late 1970s through the early 1990s which met with limited success. A more preferred and approach is one adopted where such improved varieties e.g. of bananas or sweet potatoes form part of a more holistic composite recipe or diet, and in which the ingredients constituting such a diet are carefully chosen based on their 'individual nutrient strengths' to complement each other and provide an enriched composite product through food-to-food fortification.

Empirical evidence suggests that nutrients in food tend to naturally interact with each other and to complement each other in their function[11-12]. For instance, ascorbic acid (vitamin C) from citrus fruits promotes absorption of non-haem iron in plant-based foods e.g. cereals and banana[13-18]. Similarly, protein, vitamins A, B_6, B_{12} and E; and the minerals iron, copper and zinc which play various important roles in the formation of healthy red blood cells and preventing anaemia[19-20] can be extracted from a combination of plant and animal-based food ingredients. Thus employing a food-based approach to prevent and / or address nutritional needs of vulnerable groups is a more cost-effective and sustainable means to improving nutrition in poor communities[21-24]. On the other hand, a meal which focuses on ingredients providing one or two nutrients but lacks diversity does not create a balance involving other nutrients and will not provide the full complement of nutrients required for optimum health. In this paper we examine the application of the Food Multimix (FMM) concept to address such nutrient gaps and improve nutrition in a sustainable way are discussed.

The Food Multimix concept

We define a food multimix (FMM) as *a blend of locally available, affordable, culturally acceptable and commonly consumed foodstuffs mixed proportionately, drawing on the 'nutrient strengths' of each component of the mix in order to optimise the nutritive value of the end-product without the need for external fortification*[25]. Doing so by harnessing local food ingredients and employing food science, technology and food product development techniques to develop edible products to meet needs within a cultural context is desirable.

The FMM concept is built on the notion that in seeking ways to improve nutrition in resource-poor environments scant local food ingredients can be harnessed effectively for recipe development to provide composite diets for multiple uses including for optimum health and therapeutic purposes. We have argued the universal application of the concept borne out of our belief that by applying knowledge of food science, human biology and nutrition, and adopting sound empirical approaches, scant food resources in resource-poor communities can be harnessed to produce nutritionally balanced recipes to help alleviate nutritional problems where chronic hunger and food-insecurity exist. The concept has previously been applied to produce nutrient-enriched recipes for clinical and population-based interventions utilising traditional food ingredients in low income communities in Africa, the details of which are described elsewhere[25-27]. This novel scientific approach to the concept of food (and meal) diversification relies on the use of scientific methods combined with traditional food technology, and tailoring food products to the needs of specific vulnerable groups within different social and cultural contexts. In combining ingredients based on their individual 'nutrient strengths', the food-to-food fortification of their components can be maximised, thus enriching and improving the nutritive value of the composite meal within the mix. Primarily traditional varieties of food crops, including cereals, grains, legumes, vegetables and fruits, and where appropriate, available and affordable, animal products have been used to simulate real life community meal preparation practices. Food recipes developed are low-cost, (average, 0.20 USD per 100 g of recipe with a target to provide up to 40% of daily energy requirements and more than 50% of daily mineral and vitamin requirements depending on age)[27]. However in rare instances where limiting nutrients are not sufficiently represented, there may be a need to add external fortificants such as mineral and vitamin pre-mixes. Recipes thus formed with known nutrient composition, are first made in powder form (can be packaged in sachets) and subsequently developed into a variety of end products including porridge, soups, cakes, bread and muffins.

The flexibility and advantage of this approach is that the combination of traditional food ingredients can be customised within any community harnessing their own available natural, affordable, culturally acceptable and commonly consumed resources within their own economic means, and taking into account their specific physiological and clinical needs for targeted interventions e.g. in pregnancy, home or community-based nutrition rehabilitation, for normal growing infants, young children, and in school feeding programmes.

Scope of application of the FMM concept in meal recipes

Over the course of a decade or more, a number of recipes have been designed to meet the nutritional needs of different population groups including general adult and school-age groups, pregnant women, HIV/AIDS patients, healthy growing older infants and children, and those undergoing nutritional rehabilitation. Some of the recipes have undergone sensory evaluation to test their characteristics and acceptability, and one randomized, controlled prospective feeding intervention trial has been completed in a cohort of pregnant women in South Africa who were followed from booking enrolment to term[27]. The research and development (R&D) activities employed have involved using scientific principles and methods whilst food processing have involved refinement of existing traditional methods. A combination of *Matlab mathematical software*^{R} and *Excel*^{R} have been employed to allow for the generation a number of possible permutations and combinations of local foods from a food composition database, to form recipes and ensure desirable nutrient composition, density and energy content. Laboratory analyses are employed to determine nutrient composition following processing of recipes analyses including proximate, for energy and macronutrients; minerals; and vitamin analyses, except where methods of vitamin analysis were not available, in which cases content was estimated using standard reference food composition databases (*See Process Flow Diagram in* Figure 1). These methods have been previously described in detail elsewhere[25-28]. Tests of organoleptic properties including texture, taste and sensory evaluation for consumer acceptability employed standard scientific protocols.

Food multimix products are based on locally available raw materials therefore the concept can be adapted to suit any environment globally[29-36]. For instance in most of East Africa, banana, plantain and sweet potatoes are commonly consumed, along with maize meal and a variety of legumes and green leafy vegetables. FMM products can be designed based on these local foods. The recipes can further be reviewed and then the process of optimization undertaken where necessary, using

Matlab^R software and applying chemometrics, in order to improve the nutrient balance and hence nutritive value of the recipe prior to developing the end product for multiple uses.

Examples of FMM design and uses

i. Optimisation of existing commercial products

An originally designed and already commercially marketed product *Super5*^{R} supplied to certain institutions in South Africa was analysed for its nutritive value following which the product was optimised applying the FMM approach. The ingredients used included cereals, legumes, vegetables, and oil. Prior to product optimisation, the carbohydrate constituted over 70 per cent of the energy source (mainly starch) with little protein and fat. Of the micronutrients, with the exception of vitamins B_1 and folate, all other vitamins in the original product were limiting, with a low index of nutritional quality (INQ, Table 1.0).

Following manipulation and reconstitution, the samples were prepared with three separate FMM-optimised product recipe options: (carrot-based, tomato-based or spinach-based) in triplicate and analysed following initial estimation of nutrient composition from food databases. Table 1.0 shows the energy and nutrient content of the original *Super5*^{R} commercial product, the average of the three reconstituted FMM-optimised *Super5* products. These are also compared with two locally manufactured Ghanaian commercial powdered products for porridge (*Weanimix and Koko*), per 100 g of product. *Weanimix* is a cereal-legume blend introduced by the Ghana Ministry of Health, Nutrition Division and UNICEF/Ghana in 1987 to improve nutrient quality of plain maize porridge used for weanlings, and Koko is a local Ghanaian fermented maize, largely carbohydrate porridge enriched with fish meal[(37)] to boost its protein content.

Table 1.0 shows the nutrient compositions of *Super5*^{R}, the FMM-optimised *Super5*^{R}, *Weanimix* and fish-enriched *Koko*. Reformulation and optimisation of *Super5*^{R} resulted in increases in the contribution of protein and fat to energy, and a drop in carbohydrate from 78.1 to 56.9 per cent of total energy per 300 g. Protein (35.9 (±0.95) g / 300 g; an increase from 13.6 to 15.6 per cent of energy); fat (9.8 (±0.26) g / 300 g; from 8.3 to 27.7 per cent of energy). The protein content of FMM-optimised *Super5*^{R} compares favourably with *Weanimix* and *Koko*. Calcium, iron, magnesium, and zinc content of the product also increased following optimisation. The total number of limiting nutrients relative to the reference nutrient intake (RNI) values for young infants and children (9-12 months and above) was also substantially less for FMM-optimised *Super5*^{R} (3 limiting) compared to *Super5*^{R} (8 limiting), *Weanimix* (7 limiting) and *Koko* (5 limiting). Calcium content was low in optimised *Super5*^{R} and *Super5*^{R} (both plant-based) with low index of nutritional quality (INQ) values compared to *Weanimix* and *Koko* (containing dairy and fish respectively). This shortfall can be overcome by adding e.g. milk to porridge made from *Super5*. The INQ, defined as (the amount of a nutrient per 4.18 MJ present in a food or meal relative to a reference standard source of that nutrient) is a measure of nutrient density and is best applied as a measure of protein and micronutrient density in composite meals. A food with overall INQ substantially greater than unity is generally considered a good source of the nutrient except for lipids which in excess, may be detrimental to e.g. cardiovascular health. An INQ value less than unity implies a need to eat more to meet the requirements for that nutrient. The INQ has the potential to serve as a useful guide for meal planning for vulnerable groups, and could be used for nutrition education, food labelling and evaluation of nutrient intake[38].

As has been shown in this example, addition of one or two other commonly consumed vegetables such as spinach, carrots, tomatoes; and oil to an existing composite product and decreasing the amounts of others e.g. the staple maize base can improve nutritional balance and quality of the diet at minimal extra cost. Although primarily plant-based diets, these foods offer enough nutrients to meet daily requirements for targeted individuals per 300 g in the absence of animal source foods. This combination of foods using their individual nutrient strengths provides further evidence that food-based approaches even involving manipulation of largely dependent on plant based sources are beneficial. This approach can be a useful means of intervention to meet nutritional needs and a useful adjunct to nutritional management of disease within hospital settings e.g. acute mental health units where patients may have limited food choices.

ii. Development of nutrient-dense weaning foods

The infantile growth spurt which occurs between 6 and 9 months is associated with rapid growth, increased levels of physical activity and physiological changes. Expansion in blood volume and haemodilution may result in physiological anaemia in otherwise healthy infants, but symptomatic, clinical anaemia in high risk infants with low haemoglobin or iron stores. Increasing demands for energy and micronutrients also occur and breast milk alone is insufficient to meet such growing demands, hence the need for the gradual introduction of appropriate complementary foods. In many food insecure communities, breast-milk is often complemented with plain home-made porridge low in energy and nutrient density, and poor nutritional quality made from local staples such as maize and plain white rice. Early signs of protein-energy malnutrition are characteristically seen as early as the sixth month of life in such circumstances. The risk of malnutrition is made worse by poor feeding practices during this transitional or weaning period, contributing to childhood morbidity and mortality. The application of the FMM concept in meal planning for this age group is therefore an attempt to help mitigate potential shortfalls in nutritional adequacy of diets in an otherwise high risk vulnerable group.

In Table 2.0, which we provide a rationale for developing low cost complementary foods for use in a local context. Figure 2.0, also shows findings from FMM recipes developed for 9 – 12 month old weanlings employing local foods commonly consumed in some communities in Malaysia[39] and taking into account their energy needs per kilogram of body weight. The average recipe contains at least 40% of the total daily requirement of energy for this age group with a good balance of carbohydrate, fat and protein in the diet, which can be fed as a weaning complement to breast milk. With the exception of calcium and zinc, 100 g of the recipes provided in excess of 90% of RNI values for essential vitamins and minerals. Liver which forms an integral part of the average diet, and which is a component of the recipes will also act as a rich source of animal source protein, iron and vitamin A. This rich balance of nutrients in a complementary food for weanlings was derived from commonly consumed local ingredients in relatively poor Malaysian poor communities with limited resources.

iii. Supplementary and therapeutic foods nutritional support

Nutritional support is important for the sick child, and especially the undernourished being treated in hospital or the community. The types of foods and their nutrient composition will depend upon the type, nature and stage of malnutrition and rehabilitation, and whether supplementary or therapeutic foods are the intended target. In the design of FMMs for nutritional support, metabolic challenges of malnutrition are taken into account in formulating mixes including meeting energy, protein and micronutrient needs e.g. exercising caution in the provision of iron in the diet especially during the early phase of treatment for severe acute malnutrition (SAM). The data presented in Table 3.0 represent a range of low-cost micronutrient-dense local foods, selected to ensure familiarity and cultural acceptability whilst maintaining food diversification. FMMs were formulated at different energy densities and 'nutrient strengths' (i.e. lower-strength and higher-strength) based on the WHO "Ten Steps" rationale[40] and taking into account different nutritional needs of children at different stages of rehabilitation. The recipes were processed into edible products including cookies, biscuits, cakes, porridge, and soups to allow for variety in the diet. The results of the nutrient compositions are comparable with both *Weanimix* and *Koko,* previously described above.

iv. Complementary food products for pregnant women in a resource-poor community

To further demonstrate the universal applicability of the FMM concept, we showcase data from recipes designed and developed into end products for pregnant women in a poor community in the Gauteng Province of South Africa with a low birth weight prevalence of 16% (compared to the South African average of 11.5%)[41] in a four-month feeding trial. Optimum health and successful pregnancy outcome depend on good maternal health and adequate nutritional provision to meet foetal demands throughout pregnancy, and pregnancy weight gain is a good predictor of pregnancy outcome[42].

In designing complementary foods for pregnant women, the factorial approach in which the extra needs imposed by pregnancy and lactation are added to 'normal' baseline requirements for the non-pregnant woman formed the basis for formulations of FMM for this target group. For instance, total maternal weight gain throughout pregnancy would range from 11 – 16 kg with an extra energy cost ranging from 78 MJ (in a typical food-insecure developing country) to 281 MJ (in a food-secure developed country)[43]. In addition to energy needs, protein, minerals and vitamin requirements are expected to increase during pregnancy, the latter two particularly being affected by increased blood volumes which produce a dilutional effect.

One hundred and twenty eligible pregnant women of similar baseline nutritional and health characteristics recruited at booking, were randomly assigned in a double-blind trial to one of two groups following baseline assessment of their normal daily energy and nutrient intakes. The intervention (treatment) group received FMM complementary food (formulated high energy, high protein, micronutrient-dense food of known nutrient composition) in addition to their normal daily diet; the control (placebo) group received a commercially sold soup powder (of known nutrient composition) commonly consumed by pregnant women in the community. A 4-month feeding trial was conducted among the two groups. Outcome indicators included weight gain, haematological indices, and birth weight of babies[39] born to the two groups.

Table 4.0 shows comparisons of food intake in the intervention and control group. No significant differences in energy ($p=0.36$) and protein intake ($p=0.61$) were observed between intervention (FMM) and control (placebo) groups. Significant differences were observed in mineral intake except for selenium ($p=0.59$). Higher intakes of calcium ($p<0.001$), magnesium ($p<0.001$), zinc ($p<0.001$), copper ($p<0.001$) and iron ($p=0.03$) were observed in the treatment group. Similarly higher intakes of vitamins thiamine ($p<0.001$), niacin ($p<0.01$) and folate ($p<0.001$) were observed in the treatment group. Although differences in magnitude were observed for vitamins A, riboflavin and vitamin $B_{12,}$ these were not statistically significant (Table 4.0).

We have previously reported differences in biochemical variables[39] which are presented in Table 5.0, which shows differences in haemoglobin, iron and transferrin from baseline to post-intervention period for the intervention and control group. The control group showed no significant differences at baseline and post-intervention for most of the haematological indices[39].

Similarly for birth outcomes, we have previously shown results of better birth size and crown-heel length of babies born to intervention compared to the control group following FMM feeding trial (Table 6.0) including pregnancy weight gain ($p<0.001$), birth weight ($p<0.001$), head circumference ($p<0.001$) and crown-heel length ($p=0.05$). A difference in incidence of low birth weight of 8% compared to 16% was also observed in the intervention group[39].

Testing the sensory characteristics of FMM products

Sensory evaluation is an accepted part of the process of developing and getting new food products to market. A selection of forty food multimix products developed based on Ghanaian foods was tested for their overall acceptability among different age groups within the Ghanaian population[25, 26]. Volunteers varied from ages 11 to 68 years and were drawn from school pupils, students and adult from academic institutions and the Ministry of Education in Accra, Ghana. The focus of the sensory evaluation was to test their palatability, likeability and acceptance. Selected FMMs were prepared in the form of soup, soft porridge, biscuits, and cake.

Consumer Preference Testing was used as a method of rating classification answering the question ‘Which is liked best?’[44]. Acceptability was assessed based on *appearance, flavour, taste, textural properties (feel) and smell.* The testing procedures followed standard protocols used in other similar studies[45; 46].

Each sample tasted was rated on a Likert scale between 1 and 10 (where 1 = ‘completely unacceptable’, 5 = ‘partially acceptable’ and 10 = ‘completely acceptable’ was used for each variable assessed and the highest average ratings score taken as a likeability score for that variable. Further data transformation and analysis combining average scores from the different variables enabled conclusions to be drawn on the most favoured product among the target group.

Results of sensory evaluation are presented in Figures 5.0; 6.0 and 7.0[25-26; 47]. In Figure 4.0, the graphical representation shows the overall percentage of how evaluators responded to the FMM products. Of the 40 different products tested 34 were rated as acceptable, the most attractive was A4. Ninety one (91%, n=945) percent of subjects gave approval to the 34 different products with only 9% (n=94) registering their disapproval.

Sensory characteristics influencing acceptability between groups and within subjects is presented in a bar chart (Figures 5.0 and 6.0) [25-26; 47]. Overall acceptability was plotted on the x-axis on a 10 point Likert scale. Each figure presented in the results is labelled at the top with the FMM recipes A to J. Sensory perception of each taster was ranked according to product showing individual responses with respect to palatability, likeness and acceptability shown for males and females (blue bar = palatability; green bar = likeness and red bar = acceptability score). The graphical representation of the results appear to show that whereas females were attracted to recipe A, the males were more likely to accept recipe F (irrespective of age).

These results suggest that a number of factors influence the choice of FMM products across age and gender, even where food ingredients are familiar to individuals. The clear gender difference in preference of FMM products present interesting findings given the fact that subjects were given a free choice and allowed to employ their own sensory preference in selecting products for tasting. The basis for these differences in attraction to products may be unclear, however, this may seem to suggest that even within the same cultural environment, food-related behaviour and choice may have a strong gender influence and this merits further investigation. It is however also worth noting that irrespective of gender, porridge made from the different FMM recipes was overwhelmingly preferred to other product ranges e.g. cakes, biscuits and soups. The possible implications of these findings are that in meal provision in clinical and public health settings and in the design of foods (including specially designed recipes) for target groups, these factors need to be given due consideration.

Conclusion

In this paper, we have sought to demonstrate how, employing scientific empirical evidence and our understanding of food groups, combinations of foods can be harnessed and processed to provide supplementary and complementary food recipes for multiple purposes, especially in food-insecure communities. We believe these uses merit further exploration and especially the possibility of using the FMM Concept as an effective tool for developing foods for supportive purposes and therapeutic uses including in pregnancy, weaning and community-based nutrition rehabilitation.

The Concept in our view offers useful perspectives on alternatives to addressing contemporary public health nutrition challenges and can form part of a feeding programme aimed at improving nutrition among vulnerable groups in food insecure and poor communities in developing countries. The FMM concept provides opportunities to use our understanding of food science, nutrition, human physiology, biochemistry and pathological processes to provide nutritional support including in emergencies. We are encouraged by these findings, the synopsis of which have been presented here and believe there is scope for developing prototype products to targeted markets..

Acknowledgement: The authors would like to thank the University of Greenwich, UK, the Vaal University of Technology, South Africa, the Ghana Health Service for the tremendous help they offered for use of their facilities in formulating the concept and conducting all the analyses and testing the Concept without which this review would not have been possible.

Conflict of Interest: The authors declare no conflicts of interest.

Financial Support: The authors received no financial support towards this review

Authorship Contribution: FZ and PA developed the conception and design of the FMM Concept. FZ collated results from unpublished results, re-analysed and drafted the manuscript with inputs from PA, and BE. FZ had primary responsibility for final content. All authors have critically reviewed and approved the final manuscript.

References

1. Scaling Up Nutrition (SUN) (2010) Scaling up nutrition: a framework for action. Washington, DC: UNSCN.
2. FAO (2011) Combating Micronutrient Deficiencies: Food-based Approaches. Thompson, B and Amoroso L (Eds). FAO, Rome. ISBN 78-1-84593-714-0.
3. Olney DK, Rawat R, Ruel MT (2012) Identifying potential programs and platforms to deliver multiple micronutrient interventions. J Nutr **142,** 178S–85S.
4. Labrique A, Lucea MB and Dangour A (2012) The Power of Innovation. In The Road to Good Nutrition: A global perspective. 142-157. Karger. ISBN 978-3-318-02549-1.
5. Ruel, M (2012) Food Security and Nutrition: Linkages and Complementarities. In The Road to Good Nutrition: A global perspective. 24-38. Karger. ISBN 978-3-318-02549-1.
6. Bhutta ZA, Salam RA and Das JK (2013a) Meeting the challenges of micronutrient malnutrition in the developing world Br Med Bull **106** (1), 7-17. Doi: 10.1093/bmb/ldt015.
7. Ruel, M. T., Alderman, H., & Maternal and Child Nutrition Study Group. (2013) Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? Lancet **382** (9891), 536–551.
8. Stathers, T (2005) Promotion of sustainable sweetpotato production and post-harvest management through farmer field schools in East Africa Crop Protection Programme, R 8167 FINAL TECHNICAL REPORT http://sweetpotatoknowledge.org/cropmanagement/Promotion%20of%20sweetpotato%20production%20through%20Farmers%20Field%20schools%20R8167_FTR.pdf, accessed August 15, 2014
9. Attaluri S, Janardhan KV & Light A (Ed) (2010) Sustainable sweetpotato production and utilization in Orissa, India. Proceedings of a workshop and

training held in Bhubaneswar, Orissa, India, 17-18 Mar 2010. Bhubaneswar, India. International Potato Center (CIP).

10. Wambugu F & Kamanga D (Eds) (2014) Biotechnology in Africa: emergence, initiatives and future. Science Policy Reports. Springer. DOI 10.1007/78-3-319-04001-1
11. Kemm JR, (1980) "Nutrient Interactions", Nutrition & Food Science **80** (3), 5 – 7.
12. Salam RA, MacPhail C, Das JK, Bhutta ZA (2013) Effectiveness of Micronutrient Powders (MNP) in women and children. BMC Public Health **13** Suppl 3, S22.
13. Cook JD and Monsen ER (1977) Vitamin C, the common cold, and iron absorption. American Journal of Clinical Nutrition **30,** 235-241.
14. Davidsson L, Galan P, Kastenmayer P, Cherouvrier F, Juillerat MA, Hercberg S and Hurrell RF (1994) Iron bioavailability studied in infants: the influence of phytic acid and ascorbic acid in infant formulas based on soy isolate. Pediatric Research **36,** 816-822.
15. Davidsson L, Walczyk T, Morris A and Hurrell RF, (1998) Influence of ascorbic acid on iron absorption from an iron-fortified, chocolate-flavored milk drink in Jamaican children. Am J Clin Nutr **67,** 873-877.
16. Davidsson L, Walczyk T, Zavaleta N and Hurrell R (2001) Improving iron absorption from a Peruvian school breakfast meal by adding ascorbic acid or Na2EDTA. American Journal of Clinical Nutrition **73,** 283-287.
17. Diaz M, Rosado JL, Allen LH, Abrams S and Garcia OP (2003) The efficacy of a local ascorbic acid-rich food in improving iron absorption from Mexican diets: a field study using stable isotopes. Am J Clin Nutr **78,** 436-440.
18. European Food Safety Authority, (2014) Scientific Opinion on the substantiation of a health claim related to vitamin C and increasing non haem iron absorption pursuant to Article 14 of Regulation (EC) No 1924/2006. EFSA Journal **12** (1), 3514. Doi:10.2903/j.efsa.2014.3514.
19. Sight and Life (2012) Vitamins: a brief Guide. Sight and Life Press, Basel, Switzerland.
20. Reboul E (2013) Absorption of Vitamin A and Carotenoids by the Enterocyte: Focus on Transport Proteins Nutrients **5** (9), 3563-3581; doi:10.3390/nu5093563.
21. FAO/WHO (2001). Human Vitamin and Mineral requirements. Report of Joint FAO/WHO Expert consultation. Bangkok, Thailand.
22. Szymlek-Gay EA, Ferguson EL, Heath AL, Gray AR, Gibson RS. (2009) Food-based strategies improve iron status in toddlers: a randomized controlled trial 12. Am J Clin Nutr. **90,** 1541-51.
23. Harrison GG (2010) Public health interventions to combat micronutrient deficiencies. Public Health Reviews **32,** 256-266.
24. Bhutta ZA, Das JK, Rizvi A, et al. (2013b) Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? Lancet **382,** 452-477.
25. Zotor FB & Amuna P (2008) The Food Multimix Concept – new innovative approach to meeting nutritional challenges in sub-Saharan Africa. *Proceedings of the Nutrition Society* **67** (1), 98-104.
26. Zotor FB, Amuna P, Oldewage-Theron WH, *et al.* (2006) Industrial and Dietetic applications of the Food Multimix (FMM) Concept in meeting

Nutritional needs of vulnerable groups in South Africa. Academic Journal of Vaal University of Technology. **3**, 54-63.

27. Amuna P, Zotor F & Tewfik I (2004) Human and economic development in developing countries: a public health dimension employing the food multimix concept. World Review of Science Technology & Sustainable Development **1** (2), 129-137.
28. Amuna P, Zotor F, Chinyanga YT *et al.* (2000) The role of traditional cereal/legume/fruit-based multimixes in weaning in developing countries. Nutrition & Food Science **30** (2-3), 116-122
29. Oosthuizen D, Oldewage-Theron W & Ebuehi OA (2007) Sensory and shelf-life evaluation of a food multi-mix formulated for rural children in South Africa. Nigerian Institute of Food Science and Technology **25** (1), 56-66 ISSN 0189-7241.
30. Ouèdraogo HZ, Traoré T, Zéba A, *et al.* (2009). A local-ingredient-based, processed flour to improve the energy, iron and zinc intakes of young children: a community-based intervention. International Journal of Food Sciences and Nutrition **60** Suppl 4, 87-98 Doi:10.1080/09637480802502548.
31. Van Tienen A, Hullegie YM, Hummelen R *et al*. (2011). Development of a locally sustainable functional food for people living with HIV in Sub-Saharan Africa: laboratory testing and sensory evaluation. Journal Beneficial Microbes **2** (3), 193-198.
32. Amagloh FK., Weber JL, Brough L *et al.* (2012). Complementary food blends and malnutrition among infants in Ghana–A review and a proposed solution. Scientific Research and Essays **7** (9), 972-988. Doi: 10.5897/SRE11.1362.
33. Amagloh FK, Hardacre A, Mutukumira AN *et al.* (2012). Sweet potato-based complementary food for infants in low-income countries. Food and Nutrition Bulletin **33** (1) 3-10.
34. Nkengfack N, Torimiro N & Englert H (2012) Effects of Antioxidants on CD4 and Viral Load in HIV-Infected Women in Sub-Saharan Africa - Dietary Supplements vs. Local Diet. Journal International for Vitamin and Nutrition Research **82** (1), 63-72. DOI: 10.1024/03—9831/a000095.
35. Amagloh, F. K., Mutukumira, A. N., Brough, L *et al.* (2013). Carbohydrate composition, viscosity, solubility, and sensory acceptance of sweetpotato- and maize-based complementary foods. Food & Nutrition Research **57**, 18717 http://dx.doi.org/10.3402/ fnr.v57i0.18717
36. Ouédraogo HZ, Traoré T, Zèba AN *et al.* (2010). Effect of an improved local ingredient-based complementary food fortified or not with iron and selected multiple micronutrients on Hb concentration. Public Health Nutrition **13,** 1923-1930. doi:10.1017/S1368980010000911.
37. Lartey A, Manu A, Brown KH *et al.* (1999) A randomised, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6–12mo of age. Am J Clin Nutr **70,** 391–404.
38. Lee RD & Nieman DC (1993) Nutritional Assessment. Brown and Benchmark Publishers, Madison, Wisconsin.
39. Amuna P & Zotor F (2009) The Food Multimix Concept: Potential of an innovative food based approach on nutritional status in pregnant women in resource-poor communities. Ann Nutr Metab; **55** (1) :247.

40. WHO (2009) Update of Training course on the management of severe malnutrition: Facilitator guide. WHO Training Course on SAM. Geneva.
41. Adewuya, T.O (2009): Impact of a newly designed food complement (Food Multimix) on nutritional status and birth outcomes of pregnant women in the Gauteng Province of South Africa. PhD Thesis . University of Greenwich
42. Institute of Medicine (2009) Determination of Gestational Weight Gain: In Weight Gain During Pregnancy: Reexamining the Guidelines, pp 111-172 [KM Rasmusswen and AL Yaktine, editors] Washington DC, National Academy Press.
43. Durnin JVGA (1987) Energy requirements of pregnancy. An integration of longitudinal data from the Five-country study. Lancet ii 1131-1133.
44. Resurreccion AVA (1998) Consumer sensory testing for product development. Gaithersburg: Aspen.
45. Larmond E (1973) Methods for sensory evaluation of food. Publication 1284. Food Research Institute, Central Experimental Farm, Ottawa. Canada Department of Agriculture. Code 3M-36513-9:73.
46. Tomlins, K. I., Manful, J. T., Larwer, P. and Hammond, L. (2005). *Urban consumer preferences and sensory evaluation of locally produced and imported rice in West Africa*, Food Quality and Preference, **16**, 79 – 89.
47. Zotor F, Amuna P, Tetteh J & Ndanu, T (2009): Age and Gender Influences on Sensory Perceptions of Novel Low Cost Nutrient-Rich Food Products Developed Using Traditional Ghanaian Food Ingredients. Ann Nutr Metab; **54**, 247-248. Doi: 10.1159/0002264311.

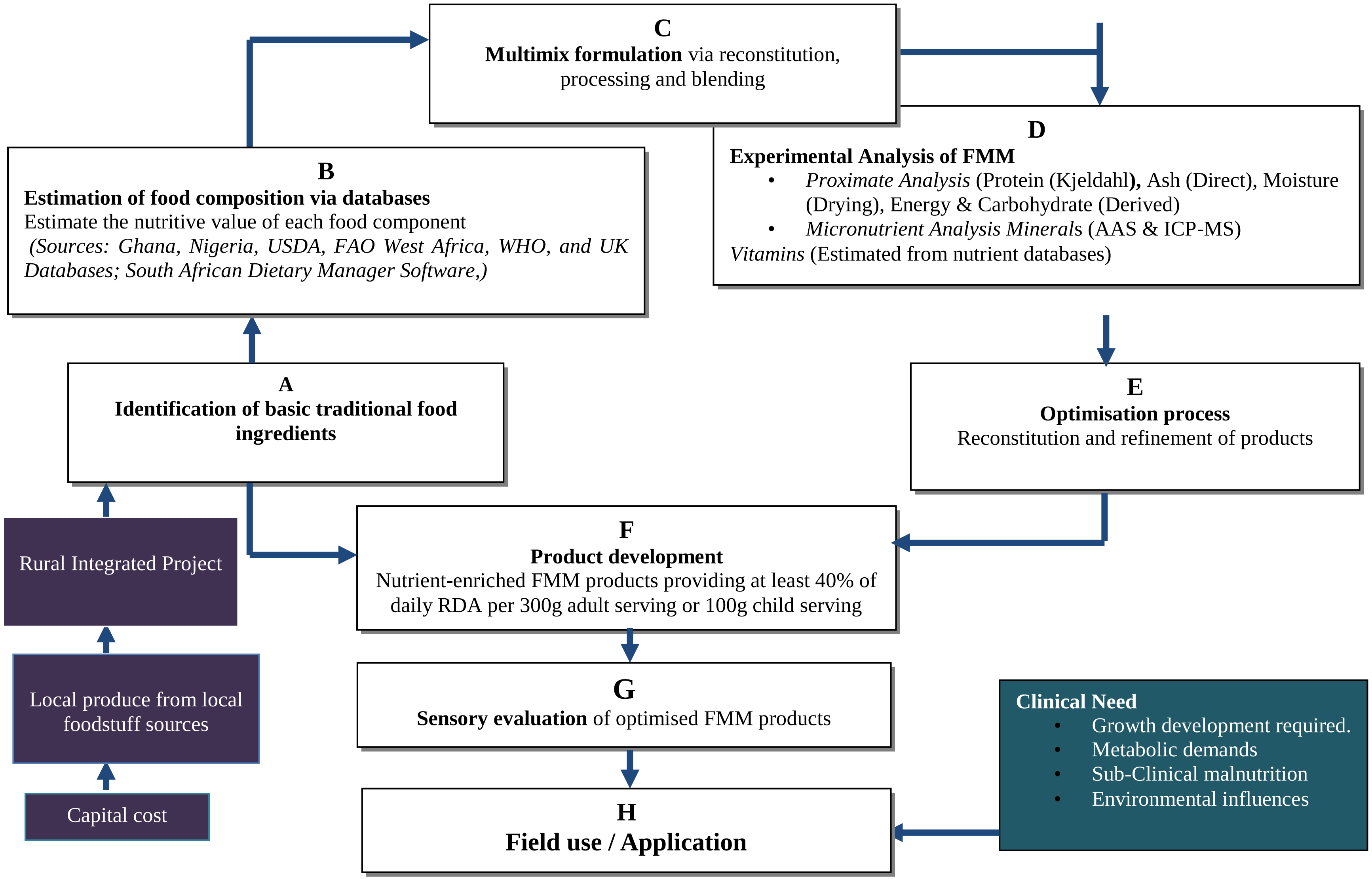

C
Multimix formulation via reconstitution, processing and blending
D
Experimental Analysis of FMM
• *Proximate Analysis* (Protein (Kjeldahl), Ash (Direct), Moisture (Drying), Energy & Carbohydrate (Derived)
• *Micronutrient Analysis Minerals* (AAS & ICP-MS)
Vitamins (Estimated from nutrient databases)
B
Estimation of food composition via databases
Estimate the nutritive value of each food component
(Sources: Ghana, Nigeria, USDA, FAO West Africa, WHO, and UK Databases; South African Dietary Manager Software,)
A
Identification of basic traditional food ingredients
E
Optimisation process
Reconstitution and refinement of products
Rural Integrated Project
F
Product development
Nutrient-enriched FMM products providing at least 40% of daily RDA per 300g adult serving or 100g child serving
Local produce from local foodstuff sources
G
Sensory evaluation of optimised FMM products
Clinical Need
• Growth development required.
• Metabolic demands
• Sub-Clinical malnutrition
• Environmental influences
Capital cost
H
Field use / Application

Fig 1.0 A schematic diagram showing the stages and processes involved in the optimisation of food multimixes (FMM) [(27)]

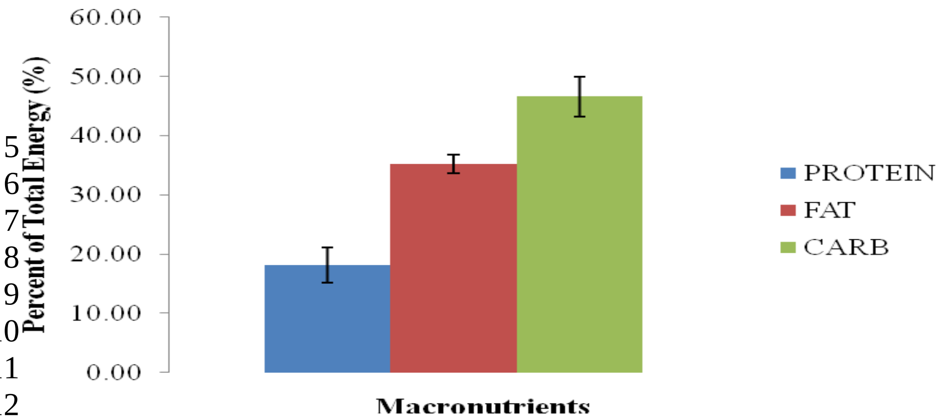
Table 1.0 Nutrient compositions of original *Super5*® food product and FMM-optimised *Super5*® per 300 g serving of product and Weanimix and fish-enriched Koko.

Multimixes	**Original FMM**[a]			**Optimised FMM**[b]										
Nutrient	Mean (±SEM)	%EAR /RNI	INQ	**Carrot based** (±SEM)	%EAR / RNI	**Tomato based** (±SEM)	%EAR / RNI	**Spinach based** (±SEM)	%EAR / RNI	AVR INQ	[C]Weanimix	INQ	[C]Koko	INQ
Energy (MJ)	4.41(±1.16)	46.9		4.92(±0.91)	52.4	4.91(±1.08)	52.3	5.17(±0.93)	55.1	--	5.46		4.86	
Protein (g)	35.9(±0.95)	71.4	0.88	41.6(±1.09)	82.75	43.0(±1.14)	85.6	56.0(±1.48)	111.3	1.4	45	1.64		3.17
Carbohydrate (g)	205.7(±5.43)	--		171.0 (±4.51)	--	169.6(±4.48)	--	167.8 (±4.43)	--		204.3			
Fat (g)	9.8(±0.26)	--		36.3 (±0.96)	--	36.0 (±0.95)	--	38.0 (±1.00)	--		34.2			
Protein (%)	13.6(±0.62)	--		14.1(±0.64)	--	14.6(±0.67)	--	18.1(±0.83)	--		13.8			
Carbohydrate (%)	78.06(±3.57)	--		58.02 (±2.68)	--	57.74(±2.64)	--	54.29 (±2.48)	--		62.6			
Fat (%)	8.33(±0.38)	--		27.78 (±1.25)	--	27.58 (±1.26)	--	27.62 (1.26)	--		23.6			
Fibre (g)	8.76(±0.23)	36.5		22.38 (±0.59)	96.6	17.28 (±0.46)	72	20.52 (±0.54)	85.5		--			
Minerals														
Ca (mg)	103.4(±2.73)	14.8	0.03	188.0(±4.96)	26.86	174.2(±4.60)	24.9	706.5(±18.66)	101	0.12	--	0.14	--	1.23
Fe (mg)	12.1(±0.32)	103.1	2.17	16.7 (±0.44)	142.1	16.9(±0.45)	144.3	31.5 (±0.83)	268.1	2.22	--	2.17	--	4.6
Mg (mg)	70.4(±1.86)	24.69	--	161.3(±4.26)	56.6	179.3(±4.73)	62.89	590.6(±15.59)	207.3	--	--	--		
Zn (mg)	9.2(±0.24)	111.6	0.35	12.8(±0.33)	152.4	12.6(±0.33)	153.1	13.7(±0.36)	165.8	0.85	--	0.35	--	1.55
Vitamins														
Folate (µg)	138.25(±3.65)	69.1	1.42	153.61 (±4.06)	76.8	173.11 (±4.57)	86.6	1280.8 (±33.82)	640.3	5.6	201	1.42	84	0.87
Thiamine (mg)	1.02(±0.03)	113.3	2.55	1.19(±0.03)	132.2	1.02(±0.03)	113.3	1.47(±0.04)	163.3	3.33	1.44	2.55	0.96	2.48
Riboflavin (mg)	0.3(±.01)	25	0.39	0.44 (±0.01)	36.7	0.54(±0.01)	45	1.41(±0.04)	117.5	1.04	0.012	0.39	0.30	0.40
Niacin (mg)	5.88(±0.16)	39.2	1.02	7.01(±0.19)	46.7	7.77(±0.21)	51.8	9.3(±0.25)	62	1.39	11.7	1.02	12.3	2.12
β-Carotene (µg)	66.23(±1.75)	10.2	0.20	1687.1(±44.54)	259.6	579.93 (±15.31)	89.2	4015.6(±106.02)	617	6.16	108	0.20	132	0.19
Vitamin C (mg)	7.35(±0.19)	18.4	0.15	30.03(±0.79)	75.1	39.06 (±1.03)	97.7	169.36 (±4.47)	423.4	1.64	0.30	0.15	0.00	0.00

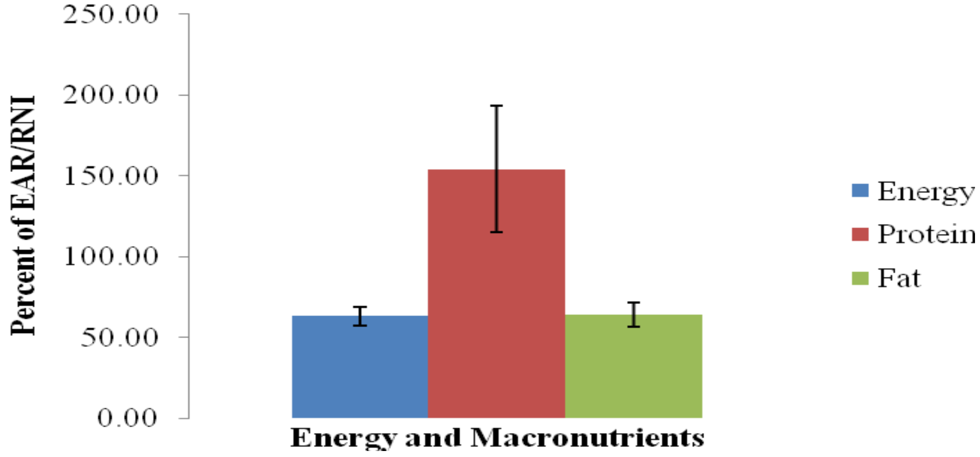
[a]*original food multimix;* [b] *carrot, spinach and tomato-based optimised products;* [C]*weanimix*: a cereal-legume blend; [C]*koko*: Fermented maize dough (fortified with fish meal [(25; 37)]

Table 2.0: Summary of the criteria for FMM formulations for Infants aged 9-12 Months

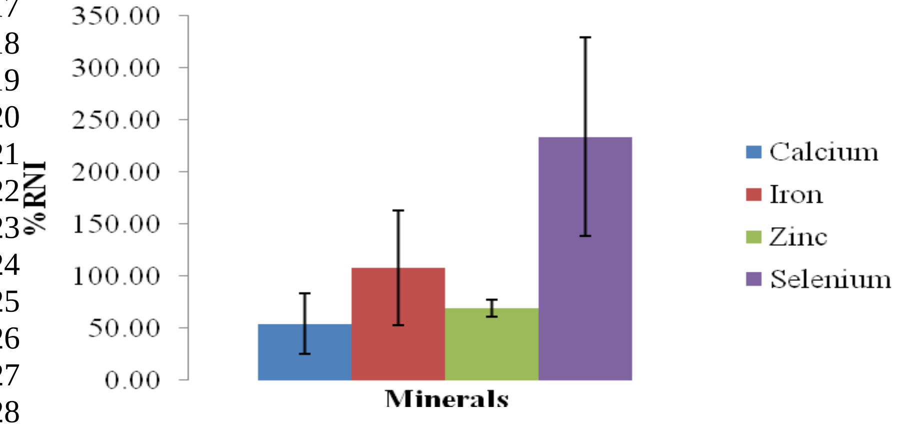
FMM Criteria Design	Rationale
Energy Density: 635kcal/day (2667kJ/day)	To prevent protein energy malnutrition and growth and development retardation.
Fat: provide 35-40% of total energy intake	To enhance energy density and provide essential fatty acids for growth and development.
Protein: 12g/day	To improve growth and development, immune function, and prevent protein energy malnutrition.
Fibre: Less than 0.5g/kg of body weight, 4g/day (Calculated by employing a reference body weight of 8kg for infant aged 6-12 months in Malaysia)	To prevent energy reduction by increasing bulk, and prevent trapping of nutrients.
Vitamins and Minerals: provide more than 40% of RNI	To improve energy utilization, enhance growth and development, strengthen immune function and prevent various deficiency diseases.



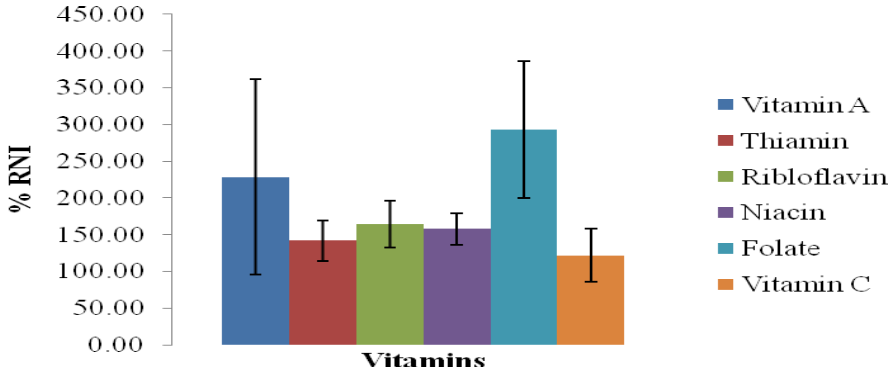
Contribution of Total Energy from Macronutrients in Food Multimixes



Percentage of RNI Achieved by Energy, Protein and Fat per 100 g Food Multimixes



Percentage of RNI Met by Minerals per 100g of Food Multimixes



Percentage of RNI Achieved by Vitamins Except vitamin B12 per 100 g of Food Multimixes

Figure 2.0: Energy, macronutrient, mineral and vitamin content of FMM designed for human weanlings 9 to 12 months old in Malaysia. EAR: Estimated Average Requirements; RNI: Reference Nutrient Intake

Table 3.0 Key nutrients in 100 g FMM per child serving compared with Ghanaian commercial products

	Nutrition Rehab†	**Nutrition Rehab‡**	**Weanimix***	**Koko****
Proximate analyses				
Energy density (kJ±SEM/g food product)	**14.6±0.19**	**16.47±0.32**	**18.18**	**16.2**
Energy distribution (%)				
Protein (g)	12.0±1.85	15.2±0.54	13.8	25.8
CHO (g)	58.2±1.61	56.6±0.29	62.6	66.0
Fat (g)	29.8±0.98	28.2±0.58	23.6	8.1
EAR/serving (%)	36.3	40.9	45.2	40.2
Mean Mineral content§				
RNI (%)	32.1	58.2	54.8	86.4
INQ	0.88	1.42	1.2	2.2
***Vitamin content¶* (%)**	**59.9**	**77.2**	**49.1**	**132.3**
INQ	1.65	1.89	1.1	3.29

¶Mean content from 7 vitamins estimated (B_1, B_2, B_3, B_{12}, folate, A & C); Nutrition Rehabilitation: 6–36 months §Mean content from 4 minerals analysed (Ca, Fe, Zn & K) Nutr. Rehab† – lower- strength; Nutr. Rehab‡ – higher-strength; Weanimix*: a cereal-legume blend introduced by the Ghanaian Ministry of Health Nutrition Division and UNICEF/Ghana in 1987 to improve food quality and Koko** (is local Ghanaian fermented maize porridge with a low energy and nutrient density that has been fortified with fish meal [25; 37].

Table 4.0: Daily nutrient intake of pregnant women consuming FMM (intervention) and placebo (control) in South Africa

	Food intake + FMM Intervention Group n = 60		Food intake + Placebo Control Group n = 60			
Nutrient	**Mean**	**±SD**	**Mean**	**±SD**	**P-value**	**DRI values**
Macronutrients						
Energy (MJ)	7.6	3.24	7.1	2.94	0.36	10.09
Total Proteins (g)	72.7	38.72	69.3	32.14	0.61	71.0
Total Fat (g)	54.9	30.87	55.0	38.09	0.98	-
Carbohydrates (g)	242.8	109.03	213.6	97.48	0.13	175.0
Minerals						
Calcium (mg)	497.4	337.40	286.5	200.83	0.00	1000
Iron (mg)	14.1	4.77	10.5	10.84	0.03	27
Magnesium (mg)	389.2	154.2	155.9	133.04	0.00	360
Zinc (mg)	10.7	4.97	5.7	5.46	0.00	11
Copper (µg)	1.6	1.24	0.8	1.14	0.00	2
Selenium (µg)	31.5	31.77	28.1	36.98	0.59	60
Vitamins						
Vitamin A, RE (µg)	1230.3	278.02	558.6	246.34	0.17	770
Thiamin (mg)	1.35	0.53	0.87	0.89	0.00	1.4
Riboflavin (mg)	1.29	1.37	0.84	1.35	0.08	1.4
Niacin (mg)	21.9	6.00	12.76	13.66	0.00	18
Folate (µg)	323.7	149.37	143.0	174.86	0.00	600
Vitamin B12 (µg)	6.1	27.77	6.8	26.15	0.90	2.6

Table 5.0 Selected haematological indices among 120 healthy pregnant women from the Vaal Triangle, Gauteng Province, South Africa, following intervention using FMM

	INTERVENTION GROUP (n=30)					**CONTROL GROUP (n=30)**					**POST-INTERVENTION GROUP (n=30)**				
	Baseline		Post-intervention			Baseline		Post-intervention			Baseline		Post-intervention		
	Mean	SD	Mean	SD	p value	Mean	SD	Mean	SD	p value	Mean	SD	Mean	SD	p value
<u>Haematological indices</u>															
Red Blood Cell ($x10^6/\mu L$)	3.90	0.36	4.50	0.45	0.15	4.10	0.45	4.19	0.54	0.47	4.50	0.45	4.19	0.54	0.30
Haemoglobin (g/dL)	10.42	0.65	10.89	1.63	0.03	10.36	0.65	9.44	0.90	0.00	10.89	1.63	9.44	0.90	0.00
Hematocrit (%)	31.13	3.24	32.18	5.40	0.96	32.57	2.61	30.71	4.57	0.20	32.18	5.40	30.71	4.57	0.17
Mean Cell Volume (L)	79.49	3.40	83.41	15.10	0.01	81.48	6.23	80.28	6.67	0.48	83.41	15.10	80.28	6.67	0.16
Iron (µmol/L)	11.71	7.32	14.21	2.24	0.04	10.28	5.79	10.78	8.12	0.86	14.21	2.24	10.78	8.12	0.01
Transferrin (g/L)	3.56	0.51	7.21	0.94	0.03	3.32	0.72	3.84	0.81	0.23	7.21	0.94	3.84	0.81	0.04
Ferritin (µg/L)	21.21	13.54	32.65	5.67	0.08	32.28	26.57	30.18	39.18	0.35	32.65	5.67	30.18	39.18	0.27

Table 6.0: Birth Size and crown-heel length of babies born to intervention and control groups following FMM feeding trial in South Africa

	Total weight gained Intervention	**Total weight gained Control**	**Birth weight (kg) Intervention**	**Birth weight (kg) Control**
Mean	11.50	10.40	3.02	2.71
SD	1.35	1.59	0.38	0.28
SEM	0.21	0.24	0.06	0.04
Median	11.30	10.20	3.20	2.80
Mode	11.10	10.40	3.20	2.80
p values	0.00		0.00	

	Crown-to-heel length (cm) Intervention	**Crown-to-heel length (cm) Control**	**Head circumference (cm) Intervention**	**Head circumference (cm) Control**
Mean	49.11	47.88	34.78	33.30
SD	2.98	2.79	1.13	1.03
SEM	0.45	0.42	0.17	0.15
Median	50.10	48.90	35.10	33.50
Mode	45.60	49.90	35.80	34.10
p values	0.05		0.00	

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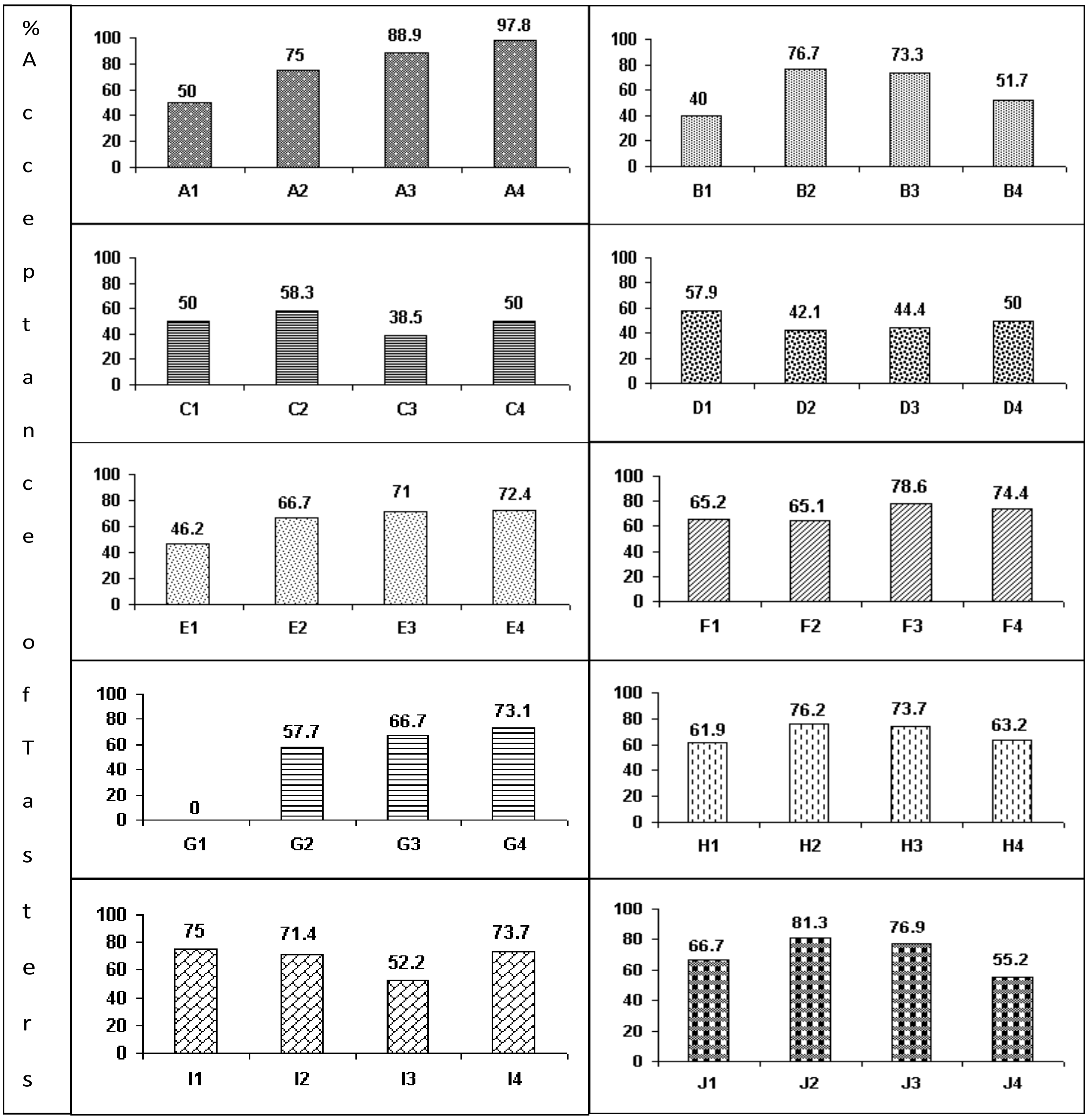

Figure 3.0 Graphical representations of sensory responses to FMM products.

(1= cake, 2=biscuit, 3= soup, 4= porridge. Composition of FMMs: A, maize-based; B, brown rice-based; C, millet-based; D, millet-based; E, carrot-based; F, tomato-based; G, sorghum-based; H, brown rice-based; I, millet-based; J, potato-based)

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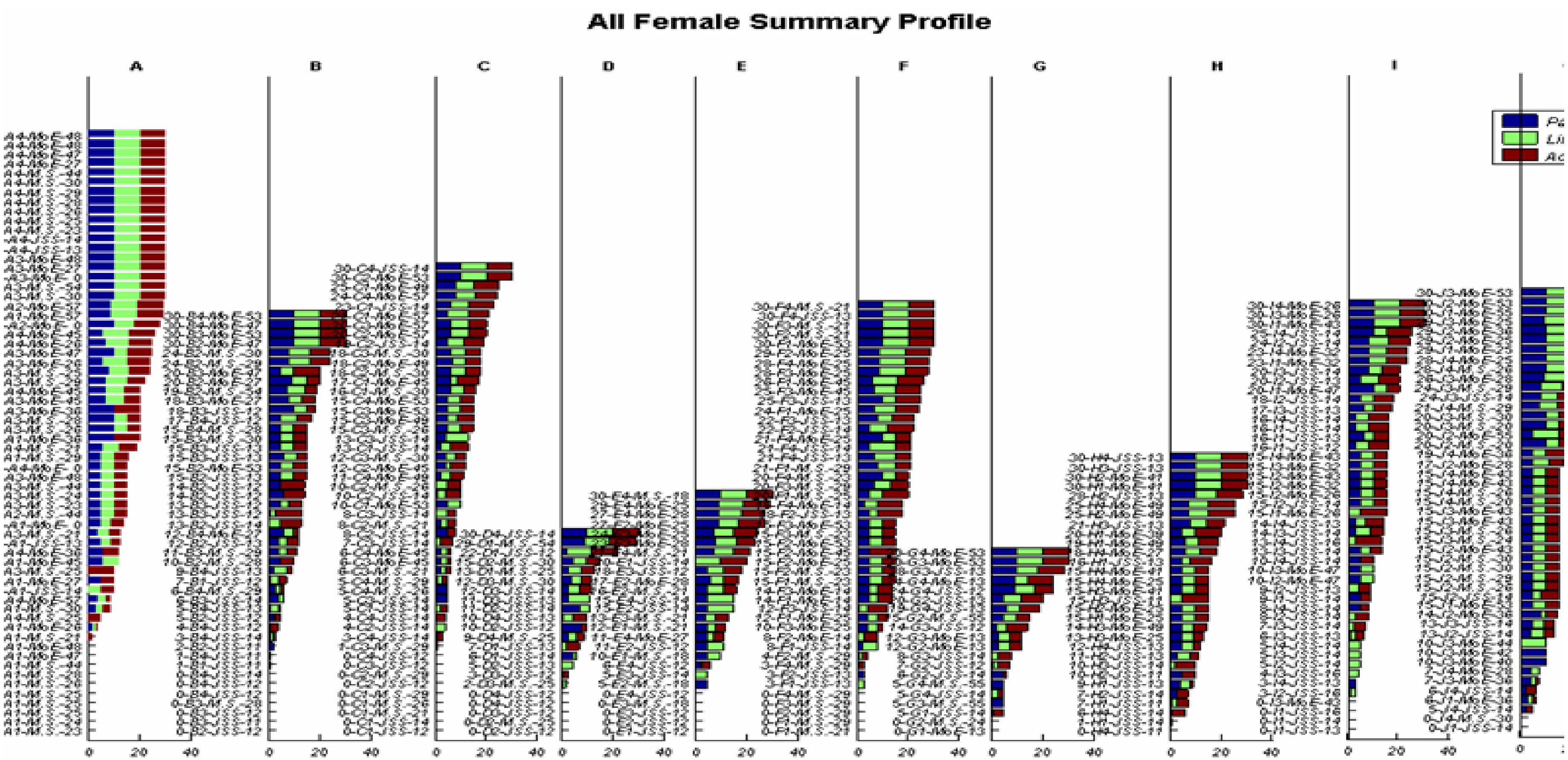

Figure 4.0 *This is a graphical representation showing individual responses on a Likert Scale of 0 – 10 with respect to palatability, likeness and acceptability shown separately (blue bar = palatability; green bar = likeness and red bar = acceptability score) of FMM products A to J tasted by all female subjects across the age range. The numerical values on the left hand side of the vertical axis represent individual subject codes (based on sum total score for PLA, product ID e.g. A4, subject group e.g. JSS and age of subjects). The size of each colour-coded bar to the right i.e. horizontal scale represents the individual score (i.e. out of a total of 10 on the Likert scale) for palatability, likeness and acceptability. The figure shows the overall distribution of tasting attractions of female subjects for the range of products provided. The tasters had freedom to try any of the products so that the number of tasters can be taken to indicate visual attractiveness.*

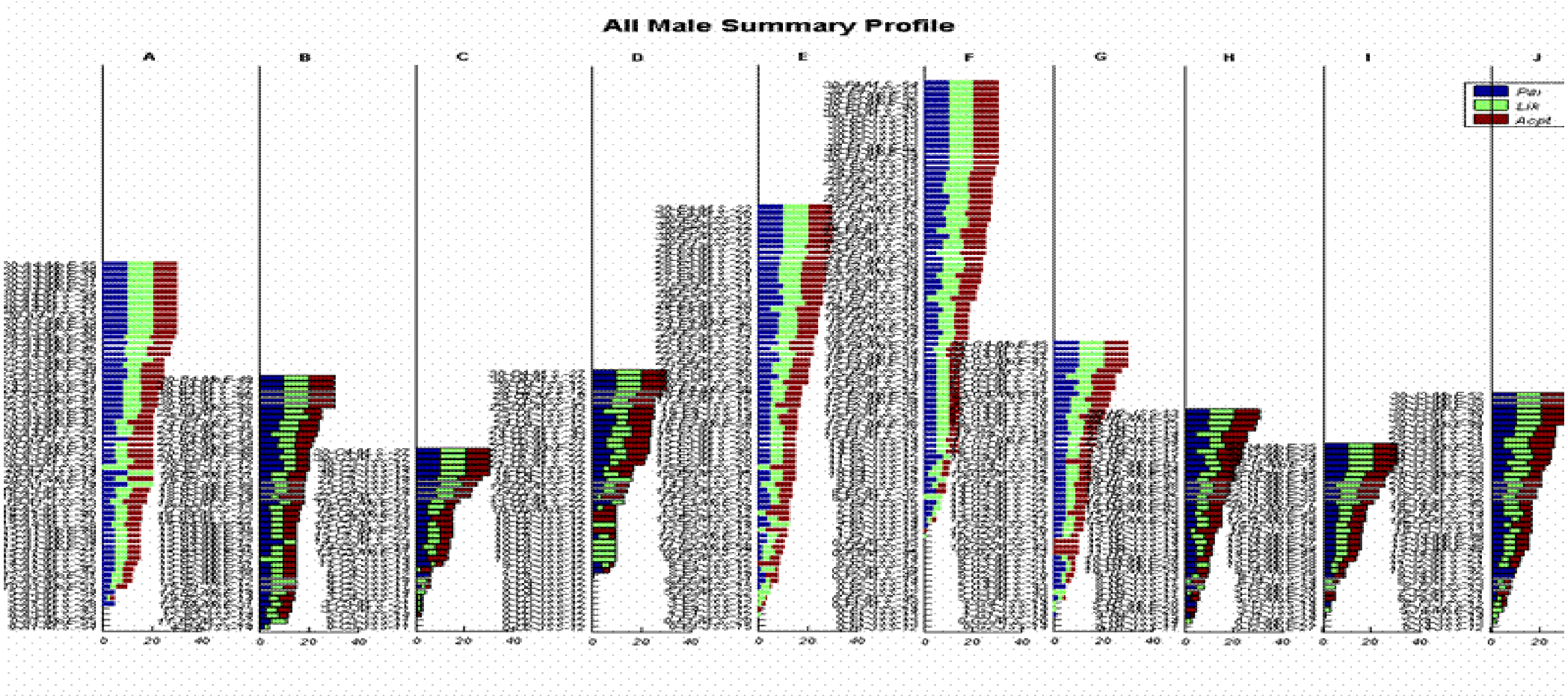

Figure 5.0 *This is a graphical representation showing individual responses on a Likert Scale of 0 – 10 with respect to palatability, likeness and acceptability shown separately (blue bar = palatability; green bar = likeness and red bar = acceptability score) of FMM products A to J tasted by all male subjects across the age range. The numerical values on the left hand side of the vertical axis represent individual subject codes (based on sum total score for PLA, product ID e.g. A4, subject group e.g. JSS and age of subjects). The size of each colour-coded bar to the right i.e. horizontal scale represents the individual score (i.e. out of a total of 10 on the Likert scale) for palatability, likeness and acceptability. The figure shows the overall distribution of tasting attractions of male subjects for the range of products provided. The tasters had freedom to try any of the products so that the number of tasters can be taken to indicate visual attractiveness.*